TILLAGE SYSTEMS FOR ROOT AND TUBER CROPS

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ABSTRACT

Although limited information is available on tillage practices for root crops, published results show that tillage methods vary widely depending upon the specific root crop, the soil type, the previous vegetation, as well as the socioeconomic conditions of farmers. These aspects are cited in this review. It was further noted that organized data for use in a classification of the tillage requirements of different soils for the various root crops is lacking. We suggest that research efforts should be directed towards the characterization of the physico-chemical, minerological, and biological factors which determine the tillage requirements of a given soil for a given root crop.

Key Words and Phrases:

INTRODUCTION

Root and tuber crops are an important food and source of calories for about one third of the world's population. They are of particular importance for the peoples of Africa, who derive about 15% of their total dietary calories from root crops; in five countries in Africa, root and tuber crops actually provide more than 40% of the calories (Horton, 1988). They also provide a substantial proportion of total calories in Oceania (7.2%), South America (6.4%), the USSR (6.2%), and Asia (5.2%).

The root and tuber crops can be divided into five major groups of crops; potato (*Solanum tuberosum*), cassava (*Manihot esculenta* Crantz), edible aroids (mainly *Colocasia esculenta* or taro and

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Xanthosomo sagittifolium or tannia), sweet potato (*Ipomoea batatas*), and yams (*Dioscorea* spp.). Botanically speaking, the edible products harvested from cassava and sweet potatoes are roots, tubers from potatoes and yams, and corms and cormels from the aroids. For simplicity the term "root crops" will be used in this paper to include all these crops.

Table 1 shows the harvested area of the various root crops in different regions of the world. Potato is by far the most important root crop, but only 18% of it is produced in the tropics, where it plays an important role in the diet, mainly for people living in the highlands. Of the tropical roots crops, cassava is the most important, followed by sweet potato, yam, and taro. In terms of total dry matter produced in developing countries, cassava is the fourth most important crop after rice, wheat, and maize (FAO, 1984; Horton, 1988).

Cassava is produced throughout the tropical regions of Africa (42%), Asia (37%), and South America (20%). Sweet potato is predominantly produced in Asia, where China alone accounts for 85% of world production. Yams are important mainly in Africa, where Nigeria accounts for 68% of total production. Taro is produced mainly in Africa (especially in Nigeria) and in Asia (mainly China), but on the basis of per capita availability it is most important in Oceania. Potatoes are produced mainly in the developed countries of Europe, North America, and the USSR; however, potato production in developed countries is declining, while that in developing countries is markedly increasing (Horton, 1988).

Root Crop Production Systems

A. Potato:

The potato is considered as a temperate zone or tropical highland crop, but the recent major increase in production in developing countries has taken place in lowland tropical areas during the cooler part of the year (Midmore, 1991). The crop, where grown commercially, receives high inputs of seed, fertilizer, and sometimes irrigation; however, as a subsistence crop it receives minimal inputs. The potato crop can generate high economic returns for commercial growers, which warrant these high inputs and its premium position within cropping systems.

B. Cassava:

Cassava is grown only in tropical and subtropical climates, up to about 28° latitude north or south, and near the equator up to an altitude of about 2,000 masl. Because of its ability to tolerate low soil fertility and droughty conditions, cassava is generally grown in areas of poor soils and under conditions of low or irregular rainfall. However, cassava is widely adaptable, and can be grown on almost any soil type, and with as little as 500 to as much as 3,000 mm. annual rainfall, the latter only if soils are adequately drained. In Africa it is principally grown in areas of degraded soils, the results of shortening fallow periods in slash-and-burn agriculture. Under these traditional systems, cassava is generally intercropped with maize, grain legumes, or vegetables, or it is grown among banana or coconuts. The crops found intermixed with cassava vary with geographical areas and cultural habits (Table 2). Monocropping characterizes the production systems of the major cassava-producing countries of Thailand and Brazil, where land preparation tends to be mechanized. However, cassava is usually grown with little fertilizer and pesticide inputs.

C. Sweet potato:

Sweet potato is a short-maturity (4-6 months) root crop, which is adapted to a wide range of growing conditions. Roots can remain in the ground for much longer and until time of utilization. Sweet potatoes are cultivated in the tropics, subtropics and in the warmer areas of the temperature zone, as well as in the tropical highlands to altitudes of up to 1,800 masl. Because of their ability to tolerate low soil fertility, sweet potatoes are often grown by small farmers on marginal land. In China and Vietnam it is usually grown as a winter crop in rotation with summer rice. In that case, it is grown on mounds or ridges in drained paddy fields with relatively fertile soils.

D. Yam:

Yams can be grown throughout the tropics, but the main center of production is in the savanna region of West Africa. Yams are rather drought resistant, but require high soil fertility. They are generally grown only in small plots and are intercropped with other food crops (Table 2). Yams are usually grown on mounds or ridges on the best soils enriched with compost or animal manure. Yam yields are markedly increased by staking. Thus, labor requirements tend to be high and yams are therefore a rather expensive but highly preferred food.

E. Taro and Tannia:

Taro and tannia (also known as cocoyam) are grown mainly in Nigeria and China as secondary crops, but form a very important part of the diet in many Pacific island countries. Tannia is shade tolerant and is thus often grown between tree crops. Taro can tolerate high soil moisture, and is grown both under upland and lowland conditions. Both species have a high water and soil fertility requirement and are therefore grown in low-lying areas with good soils. Much labor is required in land preparation, mounding and weeding.

Present Tillage Practices

Tillage practices for root crops differ from those of other crops in two aspects. First of all, root crops are usually planted rather deep and with large planting pieces compared with most cereals or legumes. They therefore do not require a very finely prepared and smooth soil surface, but grow well even if large soil clods remain on the surface; this facilitates water infiltration and reduces runoff and erosion. Secondly, root crops require considerable root expansion and thus grow best in light-textured or loose soils that are not compacted or harden upon drying. This is of particular importance if the crop is harvested during the dry season. Thus, adequate loosening of the soil during land preparation generally increases yields and facilitates the harvest; it will also result in less root or tuber damage, which in turn reduces spoilage during storage.

A. Potato:

As a large-scale commercial crop the potato is either planted on the flat or on ridges, following through plowing and discing. Recently, planting has also been promoted in paired rows on beds (Wurr, 198?). Earthing-up approximately one month after planting, to control weeds, to cover side-dressed fertilizers, and to cover stolons which encourage tuber formation, results in a ridged culture, even for plantings on the flat. At the other low-technology extreme, on the steep slopes of the Andes, where the potato was originally domesticated, the age-old traditional *tacarno*, a tool to open the sod prior to planting of an individual tuber, is still implemented. Many cultural practices within these two extremes exist, and have been adapted for specific purposes. For example, the mould-board plow or discs are preferred over the ox plow in Ethiopia, in part due to the better weed control with the former (Marian, 1987). To conserve limited soil moisture, individual tubers are either planted in small depressions (approximately 0.04 m^2) in Senegal, or they are planted on the flat and quickly covered with water hyacinth mulch, as in Bangladesh. Both systems require only a minimal yet timely plowing.

Where introduced recently, the potato is sometimes intercropped together with yams, maize, beans, and cassava on large raised mounds (as in the highlands of Cameroon), which have been previously prepared and mixed with dry organic matter to release soil K. The traditionally unsound practice of tillage and planting perpendicular to the contour on sloping land is executed on Mindañao Island in the Philippines, primarily to avoid waterlogging conditions, which are conducive to infection by the soil-borne pathogen *Pseudomonas solanacea*.

Primarily, therefore, tillage and planting practices for the potato have evolved to improve soil aeration [the growth of the tuber is more susceptible to low concentrations of soil oxygen than is the growth of the roots (Cary, 1985)], to improve rooting depth, particularly on sandy soils in areas prone to drought (Miller and Martin, 1990), and to reduce the associated operating costs and time involved in land preparation (Sterrett and Savage, 1989).

B. Cassava:

Cassava is planted by pushing 15-20 cm long stem cuttings (or stakes) vertically or at a slanted angle into the soil, leaving the tip exposed. They can also be planted horizontally by burying the stakes completely at 5-10 cm depth.

In Asia the tillage practices used depend mainly on the farm size and availability of labor (Howeler, 1988). In areas with high population density and small farms, such as in Java, China, Vietnam, and Kerala State of India, land is generally prepared by hand using a hoe or by an animal-drawn plow. In areas with larger farms, such as in Thailand, Malaysia, and on cassava plantations in the Philippines and Sumatra, land is generally prepared by tractor, using a disc plow followed by one or two passes of a disc harrow. In Thailand, land on small farms (< 1-2 ha) is usually prepared by an animal-drawn plow (twice) and harrow in the beginning of the rainy season. On bigger farms it is done by hired tractor with a 3-disc plow (1-2 times) soon after the cassava harvest, followed by a 7-disc harrow (1-2 times) before replanting. In areas of heavier or poorly drained soils, this is sometimes followed by ridging, usually done with an animal-drawn plow (Sinthuprama, 1980; Sinthuprama and Tiraporn, 1986). In Kerala State of India, cassava stakes are planted vertically on tops of mounds made by a hoe and spaced 90×90 cm apart. On sloping land these mounds are staggered, while the fields are divided into small plots by tied ridges to reduce erosion (Nair *et al.*, 1984).

In Africa, soil preparation is usually done by hand using a hoe, or cassava is planted without any land preparation. No-till systems are successfully used in areas of sandy soils such as on alluvial deposits along rivers (IITA, 1985). Some farmers in West Africa grow up to three crops of cassava and associated crops without tillage (IITA, 1988). In forested areas, the bush is cleared and burned, after which cassava is planted with a hoe or planting stick. In savanna areas, the grass is burned before land preparation by hand. Cassava is planted on the flat, on ridges or on staggered mounds, depending on the soil type, slope, and drainage (Ezumah *et al.*, 1980; Ezumah and Okigbo, 1980). In parts of Central Africa, ridges are made up and down the slope to enhance the rapid and even discharge of run-off water (Ezumah *et al.*, 1980). Ezeilo *et al.* (1975) reported that in East Central Nigeria cassava is grown on light soils with 77% planted on hills, 11% on ridges and 11% on flat land.

In Latin America, farms tend to be larger than in Asia or Africa and most land is, therefore, prepared by tractor-mounted implements. In Brazil, cassava is generally planted horizontally in furrows about 10 cm deep. The land is generally plowed and disced to 20-25 cm depth about 30 days before planting, while it is disced again and furrowed right before planting to kill the weed seedlings. After dropping in the cassava stakes the furrows are closed. Sometimes, fertilizers are applied during furrowing. If cassava stakes are planted in contact with the fertilizers, germination may be reduced (Lorenzi *et al.*, 1980). Diaz *et al.* (1977) reported that in three of five cassava growing areas of

Colombia, land is mostly prepared by tractor. In one very mountainous zone, land is prepared with 1-3 passes of an oxen-drawn reversible plow. Figure 1 shows the details of this highly efficient plow, which is easy to transport and is effectively used to plow along the contour on slopes up to 40-50%. If slopes are even greater, planting holes (*caquelas*) of 30×60 cm are prepared by hoe and two stakes are planted per hole. Only 4% of about 300 farmers interviewed planted cassava on ridges in Colombia (Diaz *et al.*, 1977).

C. Sweet potato:

Sweet potatoes are generally grown on ridges or mounds, but are also planted on the flat. In Africa and in the Pacific islands sweet potatoes are generally grown on mounds, 2-6 cuttings per mound. After plowing or hand digging the soil to 15-20 cm depth, mounds or ridges are made 20-30 cm high and 60 cm apart. Vine cuttings are then planted 20 cm apart on top of the ridge or mound (Ghosh *et al.*, 1988). In the Philippines and India, sweet potatoes are usually planted on ridges or on the flat. Off-barring (cutting close to the planted row and throwing the soil toward the center between rows) and hilling-up with an oxen-drawn plot is used in the Philippines to control weeds during the first six weeks after planting (Villanueva, 1985b).

C. Yam:

Yams are generally grown on mounds or ridges in heavy soils, but can be planted on the flat in light soils (Onwueme, 1978; Ezumah and Okigbo, 1980; Ghosh *et al.*, 1988). In West Africa, yams are generally planted on large mounds about 50 cm high, one set per mound. The soil is thoroughly plowed or worked by hand (Ghosh *et al.*, 1988; Villanueva, 1986). The size and spacing of mounds vary with the soil type and water management (Asadu, 1989; Juo and Ezumah, 1989). In areas prone to waterlogging, large mounds, sometimes 1.3 m in diameter and 0.8 m high, may be constructed (Okigbo, 1978). The soils in these areas are usually clayey. Crops grown associated with yams are cassava (placed at the top of mounds), rice (at the base), and assorted vegetables and maize at top and/or on the crest of the mounds. In sandy soils, smaller mounds, abut 40-50 cm in diameter and 20-30 cm high are made, since bigger mounds readily collapse (Asadu, 1989).

In large plantations in Barbados and Jamaica, yam production is largely mechanized (Jeffers, 1990). After harrowing, subsoiling and furrowing, ridges are made about 1.70 m apart and yam sets are spaced 0.75 to 1.50 m on top of the ridge. Yams are also sometimes planted in trenches or pits ($30 \times 30 \times 30$ cm) filled with good soil. This practice is common in many South Pacific island countries (Coursey, 1971).

E. Taro and Tannia:

For lowland taro the soil is thoroughly puddled after soaking for several days. Cormels are then planted in the drained soil, either on the flat or on small ridges (10 cm high). Shallow flooding after establishment will enhance growth and hasten maturity (Ghosh *et al.*, 1988). For upland taro and tannia, the field is generally plowed to incorporate compost or manure, followed by harrowing and sometimes ridging or mounding.

Research on Tillage Practices

Tillage practices for root crops have not been thoroughly investigated and most research has been of an empirical nature to determine the best tillage practices for a particular soil. Still, Vine (1980) reported that cassava responded more to particular soil conditions rather than to a particular tillage practice. Little research has been conducted to define the optimum soil characteristics, such as bulk density, soil penetrability, infiltration rate, etc., for the various root crops. Moreover, these physical soil characteristics, which are affected by tillage practices, are seldom determined. Thus, most researchers conclude that root crops need a light or loose soil, but that the best method of land preparation depends on the soil type, topography, vegetation, climate and the degree of mechanization or other agronomic practices used (Seixas, 1976). In light soils (Lal, 1985) or in newly cut and burned forested areas, very little cultivation is usually required, while in heavy or compacted soils, root crops respond favorably to plowing and harrowing, and under certain conditions to subsoiling or ridging.

I. Effect of tillage on soil characteristics:

The main objective of tillage is usually to loosen the soil and incorporate weeds, crop residues, fertilizers or manures. Tillage will generally reduce the soil bulk density and mechanical impedance and increase its penetrability and permeability, thus improving internal drainage. Because of a reduction in soil aggregate size and increase in pore size, the soil water content was found to be lower in tilled than in non-tilled soil (Utomo and Guritno, 1984; Ohiri, 1984; Ohiri and Ezumah, 1990). Ridging or mounding will further expose the soil to drying and increase the maximum soil temperature as well as the diurnal temperature fluctuations (Okigbo, 1979; Utomo and Guritno, 1984). Table 3 shows that during the dry season (Experiment 1 and at four months in Experiment 2) ridging significantly reduced the soil moisture content, while in the wet season (at two months in Experiment 2) ridging increased soil moisture (Utomo and Guritno, 1984).

Mulching with rice or maize straw also significantly increased soil moisture during the dry season, while decreasing soil temperature and temperature fluctuations (Figure 2). Peanut mulch was not effective in increasing the soil moisture content nor in reducing the soil temperature fluctuations (Utomo and Guritno, 1984). Okigbo (1979) also reported that mulching decreased soil temperature, especially when planting on the flat. Mulching also reduced soil splash by 66% in bare untilled soil in Ibadan, Nigeria, it increased earthworm activity (Vine *et al.*, 1984), decreased cassava bacterial blight, reduced harvesting time, and increased yield (Okigbo, 1979).

Lal (1981) reported that cassava growth and yield were more affected by moisture stress than by high bulk density, but that high bulk density accentuated the effect of moisture stress. Lal *et al.* (1984) obtained the highest root bulking rate at a soil bulk density of 1.4 and 1.8 g/cc rather than at 1.6 g/cc, while they did not observe significant differences in root yield between no-till and conventional tillage. Ohiri (1984), however, found that zero or minimum tillage in Umudike, Nigeria, resulted in low cassava yields due to high bulk density of 1.6 g/cc and high mechanical impedance.

Godo and Yeboua (1990) reported that in southeast Cote d'Ivoire, tillage increased cassava yields on first clearing of the secondary forest, but had no significant effect in the fourth year after clearing. During this period, soil fertility, as indicated by organic matter (OM), CEC, Ca, Mg and K, declined, but this decline was more pronounced in the tilled than untilled plots. Juo and Lal (1978) also reported that tillage reduced the organic C, total N, available P and exchangeable K and Ca contents. Ohiri (1983) found that with complete tillage the organic C content decline 32% in two years, while with no or minimum tillage it declined only 23%.

II. Effect of tillage on yield of root crops

A. Potato:

Tillage, which reduces soil compaction and weed competition and improves soil structure and aeration, results in yield increases over respective controls. Emergence of stems suffers from compaction and a 10-13% reduction in stem number was noted over the 305 to 749 kPa soil strength range (MacKerron and Jefferies, 1985). Elimination of surface compaction or a plow pan, often caused by working the soil at a high water content, can be effected through plowing or subsoiling, and resulted in greater cumulative evapotranspiration and greater cumulative yield on a sandy loam soil in the Netherlands (Bouma and Van Lanen, 1989). Following subsoiling, the low soil strength may persist for several years only if soil management systems are used that avoid compaction, which could be even more severe than before (Bouma and Van Lanen, 1989). There may be no benefit in subsoiling if the evapotranspiration demand of the potato crop is satisfied either naturally or by irrigation (Miller and Martin, 1990).

Minimal or reduced tillage, although resulting in improved erosion control, quicker land preparation and less compaction, has had inconclusive effects on tuber yield. For example, in one of the two years during which rye-stubble-reduced tillage was compared with conventional tillage, yield was less by 22% in the reduced tillage treatment, although in both years that treatment resulted in a 16% reduction in potato stand (Wallace and Bellinder, 1989). In contrast, although a strip single pass with a rototiller to a depth of 20 to 25 cm reduced yield significantly compared to a chissel plowing and double discing, a single plowing and pass with a cultipacker had no effect on yield but did hasten land preparation (Sterrett and Savage, 1989). Reduced tillage, i.e., 7 vs. 20 cm tillage depth, on a 20° slope with stable soil in southern China (Lai *et al.*, 1990) did not reduce potato tuber yields, but soil erosion was reduced by 27%. On a less fertile soil in the Amazon (Roca and Midmore, 1982), following burning of a 10-year jungle regrowth on a typic Paleudult soil, rototilling prior to planting to depths of 15 and 30 cm led to significant increases in the tuber yield, over the no-till treatment, especially when lime was added before rototilling. The benefits of tillage should also therefore be extended to include the quick and effective incorporation of soil amendments, where necessary.

The incorporation of weeds is, as noted previously, effected by tillage. A single earthing-up may not be sufficient to effectively control all weed growth (Vangessel and Renner, 1990), particularly since the earthing-up must be completed well before the potato foliage covers the soil.

Land preparation need not depend upon sophisticated machinery, nor the access to a plow. Simple hand preparation of raised beds or ridges, using hoes, can be effective in land preparation for potatoes (Table 4), but care must be taken to choose the appropriate planting procedure to suit the climatic conditions. Choice of agronomic practices, e.g., mulching, relay cropping, and row direction, can complement the benefits provided by tillage and have been successfully employed for potato cultivation (Midmore, 1991).

B. Cassava:

Reports on the effect of various tillage treatments on cassava yield vary greatly, depending mainly on the soil type, previous vegetation or plot history, as well as climatic conditions during preparation and planting. In general, cassava yields were higher in tilled than untilled soil (Lal and Dinkins, 1979; CIAT, 1988b; Ezumah, 1983). No-till resulted in low root density, low dry matter and N accumulation in leaves, stems and roots (Pardales, 1985), as well as lower plant establishment and less stem weight, root number and yield in an Oxisol in Zaire (Ezumah, 1983). In contrast, no-till treatment yields on a sandy loam soil in Zaire were similar to those of the tilled treatment. Table 5 shows that zero tillage or strip preparation of a hillside soil in Mondomito, Cauca, Colombia, resulted in a significant reduction in yield compared to various other methods of soil preparation. However, the hand preparation of only planting holes (about 10% of total area) was as effective as the preparation of the whole field with oxen or rototiller (Howeler and Cadavid, 1984). Similarly, Table 6 shows that no-tillage or strip preparation reduced yields of cassava grown on a 25% slope on the

Chinese island of Hainan, while hand preparation of only planting holes resulted in similar yields as complete preparation with plow and disc harrow; the preparation of only planting holes greatly reduced the level of erosion compared with complete preparation (Zheng *et al.*, 1991). Table 7 is another example of a trial in which cassava yields were significantly reduced by a lack of adequate soil preparation in a clay-loan Oxisol in Carimagna, Colombia. For all four cultivars tested, lowest yields were obtained in the no-till plot, mainly because of excessive soil compaction, but also because of inadequate weed control during establishment. When early weed competition was not a serious problem, the effect of tillage in the same soil was not significant (CIAT, 1985).

In some cases there were no significant differences between tilled and no-till plots (Maurya and Lal, 1979; Raros, 1985). Table 8 shows that tillage practices on a newly opened hillside plot in the Philippines had no significant effect on the yield of cassava, sweet potato or taro, but zero-tillage did result in the lowest yields as well as the lowest levels of erosion in cassava and sweet potato (Abenoja and Baterna, 1982). Table 9 shows that no-tillage had no significant effect on cassava yield in mulched plots with a sandy clay loam soil in Zaire. However, in the unmulched plots, or in both mulched and unmulched plots of a clay loam soil in Kimpese, Zaire, no-tillage significantly decreased yields (Ezumah and Okigbo, 1980).

In more recent experiments on a sandy clay loam Ultisol in humid southeast Nigeria, Ohiri and Ezumah (1990) found that no-till and minimum tillage had no significant effect on cassava root yields, but significantly increased top yields in the second year, compared with conventional tillage (Figure 3).

In a few cases no-tillage actually increased cassava yields. This occurred mainly in the high-OM volcanic ash soils (typic Dystrandepts) of the Cauca Department of Colombia (Howeler, 1987) and in sandy loam soils of Thailand (Verapattananirand *et al.*, 1990; Tonglum *et al.*, 1988). Table 10 shows that in two trials in farmers' fields in Colombia, no-tillage slightly increased yields and reduced erosion. Even though cassava was grown on steep slopes, erosion was relatively light, as these soils are quite permeable due to their high OM content and friable structure. Tillage markedly increased erosion in Agua Blanca. Table 11 shows that on a sandy loam soil with gentle slope in Thailand, erosion losses were quite high, but that no tillage tended to reduce erosion, while maintaining high yields of cassava. In these light and friable soils, cassava yields can be high even without tillage as long as weeds are adequately controlled by hoeing or herbicides (Sinthuprama and Tiraporn, 1986).

On sandy clay loam soils in Rayong, Thailand, land preparation trials have been conducted for 10 years from 1979 to 1989. Treatments varied slightly from year to year, but basically compared no-tillage with oxen plowing or tractor preparation, using various combinations of a 3-disc plow and a 7-disc harrow, with or without ridging. The results obtained varied from year to year, but generally indicated that there were no significant differences among treatments or that the standard practice of using a 3-disc plow followed by a 7-disc harrow produced the highest yield. However, discing only once with a 7-disc harrow, to loosen the soil and incorporate weeds and crop residues, was also very effective and generally resulted in the lowest production costs per ton cassava roots produced (Tonglum *et al.*, 1991).

The effect of depth of land preparation on cassava yield has been investigated and generally showed that there was little or no benefit to plowing more than a 10-20 cm depth (Carpena and Silva, 1982; Loganathan *et al.*, 1975; Wargiono, 1984; Mandal and Muhankumar, 1973; Seixas, 1976). Plowing a red sandy-loam soil in Coimbatore, India to 10-20 cm depth increased cassava yields and improved soil permeability, porosity and aggregate stability (Loganathan *et al.*, 1975). Villamayor (1987) recommended for the Philippines that soils be plowed and harrowed up to 20 cm depth in fields that are cropped annually and that no land preparation may be required for several years in newly opened areas. He suggested plowing to only 10 cm depth in light soils, but to more than 20 cm depth in heavy soils. For China, Li *et al.* (1986) recommended tilling to a depth of 20-30 cm, since yields decreased 15-20% when tillage depth was less than 20 cm.

After plowing and/or discing it is often recommended to make ridges, so that cassava can be planted on top of the ridge, where it is less likely to suffer from excess water. Many researchers (Diaz, 1978; Cock, 1985; Villamayor and Reoma, 1987) recommend planting on ridges only if soils are heavy or poorly drained to avoid water logging. However, in three recent trials in Hainan Island of China, ridging had no significant effect on yield or actually decreased yields (Zheng *et al.*, 1991). Ezumah and Okigbo (1980) found that in Zaire ridging increased yields on a clay loam soil, but decreased yields in a sandy clay loam (Table 9). Similarly, ridging had no significant effect on sandy or sandy loam soils in Thailand (Sinthuprama, 1980; Tonglum *et al.*, 1991), in Ghana (Takyi, 1974), in Cruz das Almas, Brazil (Conceicao and Sampaio, 1975), in the Philippines (Villanueva, 1985a) and in India (Mandal and Mohankumar, 1973). However, ridging improved root formation, facilitated weeding, hilling, and harvesting and reduced erosion (Drummond, 1986).

Instead of planting on ridges, some farmers prefer to plant on the flat and later hill-up during weeding. Thus, Mandal and Mohankumar (1973) found that two-three earthings-up during weeding in the first 1-2 months after planting significantly increased cassava yields (Table 12). Villamayor and Reoma (1987) obtained highest yields in the Philippines with off-barring at two weeks after planting (WAP), followed by hand-weeding within the row at three WAP, and hilling-up at five and seven WAP.

C. Sweet Potato:

Sweet potato yield, as with that of other root crops, is restricted by soil compaction. Values reported by Villanueva (1985b) suggest that a bulk density of more than 1.4 g/cc will reduce storage root yield, and detailed studies by __________ showed that under compacted conditions (bulk density of g/cc) top growth flourished at the expense of tuberous root thickening. Depletion of soil oxygen can temporarily halt induction and development of storage roots, an effect which can be reversed when oxygen supply is resumed to the roots (Chua and Keys, 19___). Soil compaction may limit the supply of oxygen to sweet potato fibrous and storage roots, since under compacted soil the depletion of oxygen concentration has a relatively smaller effect on tuberous root yield than did depletion under loose soil conditions.

At the field level, loosening of compacted soil through plowing (Garcia, 1987) to a depth of 27 cm was superior to plowing to either 20 or 35 cm (Table 13). However, plowing to 27 cm an subsoiling a further 7 cm resulted in superior yields, most likely because the strata below 20 cm, which was low in P and K, was not inverted by subsoiling. The frequently reported superiority of planting sweet potatoes on ridges, raised beds or mounds rather than on the flat (Wood, 1937; Ravindran and Mohankumar, 1985, Table 14; Midmore, unpublished, Table 15), whether prepared by bullock or hand (Labra and Forio, 1982), most likely reflects the enhanced soil aeration, resulting from both a greater soil surface to soil volume ratio and a lower bulk density. Although the preparation of land required more labor than planting on the flat, near compensation in labor requirement for harvest was achieved (Ravindran and Mohankumar, 1985).

Further evidence for the detrimental effect of soil compaction on sweet potato yields was afforded by trials in the Philippines (Abenoja and Baterna, 1982). While erosion was least for zero tillage, root yields were reduced below those of tilled treatments (Table 8). With the reported slope (50-60%), it is unlikely that waterlogging was responsible for the inferior zero-tillage yield.

D. Yam:

Yams are generally grown on mounds or ridges, especially in heavy soils with danger of waterlogging (Onwueme, 1978; Juo and Ezumah, 1989). Figure 4 shows that in PRCRTC in Leyte, Philippines, the planting of yam (*D. alata*) on mounds produced much higher yields than planting on ridges, on the flat, or in furrows (Villanueva, 1986). However, Morgan (1955) reported that planting on ridges produced higher yields than planting on mounds. On sandy soils of Nigeria no significant differences were observed between planting on ridges, mounds, or on the flat (Lal and Hahn, 1973; Maduakor *et al.*, 1984). Vine *et al.* (1984) reported that on a sandy Alfisol in Ibadan, Nigeria, mounding or ridging delayed emergence and vine growth and caused a slumping and compaction of the soil after heavy rain storms.

Figure 5 shows that yam tuber yields obtained in three soils in southern Nigeria increased very markedly with the increase in the size of mounds. In all three soils, both with and without fertilizers, highest yields were obtained with the biggest mound (1.5 m diameter and 30 cm high), and lowest yields when planted on the flat. The effect of size of mounds was greater in gravelly compared with gravel-free soil, and was greatest when fertilizers were applied. Highest yields were obtained in Alagba soil, which has a bulk density of 1.43 g/cc at 0-15 cm depth and 1.46 g/cc at 15-30 cm depth, with no gravel. Both the Ibadan and Egbeda soils had a high bulk density of about 1.7 g/cc in the subsoil, which also contained a significant amount of gravel (Kang and Wilson, 1982). Ohiri and Nwokoye (1984) reported that the optimum bulk density for yam is 1.10-1.36 g/cc, while the optimum porosity is between 46 and 56%.

Application of mulch increased yam tuber yields by 20% on sandy loam Ultisols in Nigeria (Maduakor *et al.*, 1984; Opara-Nadi and Lal, 1987). This is believed to be due to reduced soil-water evaporation and lower soil temperatures during the early part of the season (Lal and Hahn, 1973; Opara-Nadi and Lal, 1987a, 1987b). Mulching also reduced soil splash and increased the earthworm activity, thus reducing the soil bulk density (Vine *et al.*, 1984). It also improved soil structure and related properties (infiltrating rate, reduced bulk density over a long period (13 years) (Obi and Nnabude, 1988).

E. Taro and Tannia:

Villanueva (1986) investigated the effect of tillage intensity on production of upland taro, and found no significant differences between one or two times plowing and harrowing. Gosh *et al.* (1988) recommend one plowing with incorporation of farmyard manure, followed by harrowing, and if necessary, either mounding or ridging. Pardales and Villamayor (1983) also found that in the Philippines one plowing and harrowing was sufficient for taro production. However, Enyi (1967) reported that cocoyams (*Xanthosoma* spp.) produce better when planted on ridges, where better shaped corms are obtained (Onwueme, 1978). However, in sandy Ultisols in southeastern Nigeria no significant differences were obtained between planting on ridges or on the flat (Hullugalle *et al.*, 1985).

In Hawaii, taro is usually grown in puddled flooded soils with high inputs of fertilizers, resulting in very high yields of up to 60 t/ha (Plucknett *et al.*, 1973). Ridging of the puddled soil did not significantly increase yields (Ezumah and Plucknett, 1982), and puddling may not be necessary as long as flooding conditions can be maintained. Thus, soils in Hawaii are often prepared and planted with conventional dry-land implements and the fields are only flooded after planting (Plucknett *et al.*, 1973).

CONCLUSION

Tillage practices for root crops vary widely, depending on the particular crop, the soil type, and the previous vegetation, as well as the socio-economic conditions of the farmers. For crops grown in small-sized plots, such as yams, taro, tannia and occasionally cassava, sweet potato and potato, the tillage practices are usually limited to clearing the previous vegetation and loosening of the soil by hoe in the planting hole or throughout the planted area. On medium-size farms, land is usually prepared with oxen-drawn plows, while in larger extensions two-wheel and four-wheel tractors are used with plow, disc harrow, rototiller and sometimes ridger.

Research on tillage practices for root crops is limited, but generally shows that cassava requires only a minimum amount of land preparation when grown on sandy or high-OM soils, or on soils recently cleared from natural vegetation. In medium-textured or compacted soils, one or two plowings followed by disc harrowing is usually sufficient to incorporate weeds and crop residues, while loosening the soil enough to facilitate planting, root formation and harvesting. In heavy soils or in areas of high rainfall, it is recommended to plant on ridges. Sweet potato, potatoes and yams are usually grown on ridges or mounds after thorough plowing and discing or digging of the field. Organized information for use in a classification of the tillage requirements of different soils for the various root crops is badly needed.

Minimum tillage, in which only the soil in the planting holes is prepared, or in which contour-prepared strips are alternated with unprepared strips, is often recommended for light or friable soils, in order to reduce production costs and erosion. However, these practices are less effective for weed control, and high yields can only be expected if weed competition is minimized. Contour ridging and mulching are other practices that may increase yields, while drastically reducing soil losses by erosion. Research on *in situ* growing of mulching materials, the development of better implements such as oxen-drawn plows and ridgers, and the selection of cheaper and more effective herbicides, are required to facilitate the wider adoption of no-till or minimum tillage practices among root crop farmers, both to reduce production costs and to conserve our soil resources for future generations.

REFERENCES

Abenoja, E.A. and J.P. Baterna (1982). Tillage practices in continuous hillside farming of root crops. *Radix* 4, 9-11.

Asadu, C.L.A. (1989). Soil Environment and Yam Production in Three Ecozones of Nigeria. Unpublished Ph.D. thesis, University of Nigeria, Nsukka, Nigeria.

Bouma and Van Lanen. (1989).

Camacho, G.H. (1985). Uso de maquinaria en suelos de ladera con fines conservacionistas. In *Manejo y Conservacion de Suelos de Ladera*, R.H. Howeler (ed.), Memorias Primer Seminario Sobre Manejo y Conservacion de Suelos. June 14-16, 1984, Cali, Colombia. Sociedad Colombiana Ciencia del Suelo, pp. 122-128.

Carpena, C., F.L. da Silva, and L. da Silva (1982). Manejo e conservacao do solo para a cultura da mandioca. In *Proceedings of the 4th Curso Intensiva Nacional de Mandioca*, Cruz das Almas, Bahia, Brazil.

Cary. (1985).

Centro Internacional Agricultura Tropical (CIAT). (1985). *Annual Report for 1982 and 1983.* Cassava Program, CIAT, Cali, Colombia.

Centro Internacional Agricultura Tropical (CIAT). (1988). Cassava Program Annual Report 1986, Working Document No. 43, CIAT, Cali, Colombia.

Cock, J.H. (1985). *Cassava. A New Potential for a Neglected Crop.* Westview Press Inc., Boulder, Colorado. 192 pp.

Conceicao, A.J. da and C.V. Sampaio. (1975). Sistemas de plantio de mandioca. In *Projeto Mandioca, Cruz das Almas, Brazil.* Convenio U.F. Ba/BRASCAN Noreste. Serie Pesquisa Vol. 2, No. 1, pp. 119-127.

Coursey, D.G. (1971). The history and possible future of yam cultivation in West Africa. In *Proceedings of the Seminar on Root and Tuber Crops in West Africa*, Feb. 22-26, IITA, Ibadan, Nigeria. ____ pp.

Chua and Keys. (19____).

Danniya, M. (1989). Cassava production systems in Sierra Leone. Discussion paper, Cassava-Based Cropping Systems Annual Meeting, Cape Coast, Ghana.

Diaz, D.A. (1978). Land preparation for cassava. In *Cassava Production Course*, C. Dominquez (ed.). CIAT, Cali, Colombia, pp. 84-90.

Diaz, R.O., J.C. Toro, and U. Varon. (1977). Caracteristicas de la produccion y sistemas de siembra. In *Descripcion Agroeconomica del Proceso de Produccion de Yuca en Colombia*, R.O. Diaz and R. Pinstrup-Andersen (eds.). CIAT, Cali, Colombia. 20 pp.

Drummond, O.A. (1986). *Plantio de Mandioca em Camalhoes*. Empresa de Pesquisa Agropec. de Minas Gerais, Pesquisando No. 171. Belo Horizonte, MG, Brazil. 4 pp.

Enyi, B.A.C. (1967). Effects of age on establishment and yield of cocoyam sets (*Xanthosoma sagittifolium* Scott). *Expl. Agric.* **3**, 121-127.

Ezeilo, W.N.O., J.C. Flinn, and L.B. Williams. (1975). *Cassava Producers and Cassava Production in the East Central State of Nigeria*. National Accelerated Food Production Project, Cassava Benchmark Survey, East Central State. Ibadan, Nigeria. 27 pp.

Ezumah, H.C., ed. (1980). *Cassava Production and Extension in Central Africa*. Proc. Series No. 4, IITA, Ibadan, Nigeria. 280 pp.

Ezumah, H.C. (1983). Agronomic considerations of no-till farming. In *No-Tillage Crop Production in the Tropics*, I.O. Akobundu and A.E. Deutsch (eds.). Oregon State University, Corvallis, OR, USA, pp. 102-110.

Ezumah, H.C., R. Lal, and B.N. Okigbo. (1980). Soil and water conservation and management for cassava production in Africa. In *Cassava Cultural Practices*, E.J. Weber, J.C. Toro, and M. Graham (eds.). Proceedings of a Workshop, March 18-21, 1980, Salvador, Bahia, Brazil. IDRC-151e, Ottawa, Ontario, Canada, pp. 70-74.

Ezumah, H.C. and B.N. Okigbo. (1980). Cassava planting systems in Africa. In *Cassava Cultural Practices*, E.J. Weber, J.C. Toro, and M. Graham (eds.). Proceedings of a Workshop, March 18-21, 1980, Salvador, Bahia, Brazil. IDRC-151e, Ottawa, Ontario, Canada, pp. 44-49.

Ezumah, H.C. and D.L. Plucknett. (1982). Cultural studies on taro (*C. esculenta*): Age and moisture effects on growth and corm yield. *J. Root Crops* 8, 17-26.

Ezumah, H.C., F.I. Nweke, N.D. Kalabare, and A. Karunwi. (1988). Response of cassava-maize intercrop to nitrogen in two-year sequential cropping. In *Cassava-Based Cropping Systems Research 1*, IITA, Ibadan, Nigeria.

Food and Agriculture Organization of the United Nations (FAO). (1984). *FAO Production Year Book 1983,* WHERE PUBLISHED??

Food and Agriculture Organization of the United Nations (FAO). (1990). *FAO Production Year Book 1989,* WHERE PUBLISHED??

Garcia. (1987).

Ghosh, S.P., T. Ramanujam, J.S. Jos, S.N. Moorthy, and R.G. Nair. (1988). *Tuber Crops.* Oxford and IBH Publishing Company, New Delhi, India. 403 pp.

Godo, G. and K. Yeboua. (1990). Cassava yield trend and the dynamics of soil chemical parameters in Southeastern Cote d'Ivoire. In *Proceedings of the 8th Symposium Intern. Soc. Trop. Root Crops*, Oct. 30–Nov. 5, Bangkok, Thailand, pp. 237-242.

Horton, D. (1988). *Underground Crops: Long-term Trends in Production of Roots and Tubers.* Winrock International Inst. Agric. Devel., Morrilton, AR, USA. 130 pp.

Howeler, R.H. (1987). Soil conservation practices in cassava-based cropping systems. In *Proceedings of the International Conference Steepland Agriculture in the Humid Tropics*, T.H. Tay, A.M. Mokhlaruddin and A.B. Zahari (eds.), Aug. 17-21. Kuala Lumpur, Malaysia, pp. 490-517.

Howeler, R.H. (1988). Agronomic practices for cassava production in Asia. In *Cassava Breeding and Agronomy Research in Asia*, R.H. Howeler and K. Kawano (eds.). Proc. Regional Workshop, Oct. 26-28, Rayong, Thailand, pp. 313-340.

Hullugale, N.R., R. Lal, and O.A. Opara-Nadi. (1985). Effect of tillage system and mulch on soil properties and growth of yams (*Dioscorea rotundata*) and cocoyam (*Xanthosoma sagittifolium*) on a Ultisol. *J. Root Crops* 11, 9-22.

International Institute of Tropical Agriculture (IITA). (1983). *Annual Report for 1982.* Ibadan, Nigeria.

International Institute of Tropical Agriculture (IITA). (1986). *Annual Report for 1985.* Ibadan, Nigeria.

International Institute of Tropical Agriculture (IITA). (1989). *Annual Report for 1988.* Ibadan, Nigeria.

Jeffers, J.P.W. (1990). Mechanized production of yam in Barbados. In *Proceedings of the 8th Symposium International Society Tropical Root Crops*, R.H. Howeler (ed.), Oct. 30-Nov. 5, Bangkok, Thailand, pp. 642.

Juo, A.S.R. and H.C. Ezumah. (1989). Mixed root crop ecosystems in the wetter regions of sub-Saharan Africa. In *Food Crop Ecosystems of the World*, C.J. Pearsen (ed.). Elsevier Scientific Publications, Amsterdam, Netherlands (*in press*).

Juo, A.S.R. and R. Lal. (1978). Nutrient profile in a tropical Alfisol and no-till system. *Soil Sci.* 127, 168-173.

Kang, B.T. and J.E. Wilson. (1982). Effect of heap size and fertilizer application on yam (*Dioscorea rotundata*) in Southern Nigeria. In *Proceedings of the 5th Symposium International Society Tropical Root Crops*, E.H. Belen and M. Villanueva (eds.), Sept. 17-21, Manila, Philippines, pp. 245-258.

Labra, J.S. and A.F. Forio. (1982). Economical seed bed preparation for sweet potato. *Radix* 4, 5-6.

Lal, R. (1990).

Lal, R. (1985). _____??_____. *Soil Tillage Research* 5, 179-196.

Lal, R. (1981). Effects of soil moisture and bulk density on growth and development of two cassava cultivars. In *Proceedings of the 1st Triennial Symposium International Society Tropical Root Crops – Africa Branch*, Sept. 8-12, Ibadan, Nigeria, pp. 104-110.

Lal, R. and E.L. Dinkins. (1979). Tillage systems and crop production on an Ultisol in Liberia. In *Soil Tillage and Crop Production*, R. Ral (ed.). IITA, Ibadan, Nigeria, Proc. Series No. 2, pp. 221-233.

Lal, R., B.S. Ghuman, and H.O. Maduakor. (1984). Effects of soil moisture, bulk density, and tillage treatments on tropical root crops. In *Proceedings of the 6th Symposium International Society Tropical Root Crops*, Feb. 21-26, Lima, Peru, pp. 618.

Lal, R. and S.K. Hahn. (1973). Effect of method of seed bed preparation, mulching, and time of planting on yam in Western Nigeria. In *Proceedings of the 3rd Symposium International Society Tropical Root Crops*, Ibadan, Nigeria, pp. 293-298.

Li, F., X. Lin, and X. Tang. (1986). Cassava in the agricultural economy of China. In *Cassava in Asia: Its Potential and Research Development Needs*, Proc. Regional Workshop, June 5-8, Bangkok, Thailand, pp. 59-63.

Longanathan, S., V. Ravikumar, and K.K. Krishnamoorthy. (1975). Studies on the conjoint effect of tillage and soil amendments on the yield of tapioca and physical properties of soils. *Madras Agric. J.* **62**, 248-252.

Lorenzi, J.O., E.S. Normanha, and A.J. de Conceicao. (1980). Cassava production and planting systems in Brazil. In *Cassava Cultural Practices*, E.J. Weber, J.C. Toro, and M. Graham (eds.), Proc. Workshop, March 18-21, Salvador, Bahia, Brazil. IDRC-151e, Ottawa, Ontario, Canada, pp. 38-43.

Lutaladio, N.B. (1986). Planting period and associated agronomic practices for cassava (*Manihot esculenta*) production in Southwestern Zaire. Unpublished Ph.D. thesis, University of Ibadan, Ibadan, Nigeria.

MacKerran and Jefferies. (1985).

Maduakor, H.O., R. Lal, and O.A. Opara-Nadi. (1984). Effects of methods of seedbed preparation and mulching on the growth and yield of white yam (*Dioscorea rotundata*) on an Ultisol in southeastern Nigeria. *Field Crops Research* **9**, 119-130.

Mandal, R.C. and C.R. Mohankumar. (1973). A note on response of tapioca to variable tillage. *Indian J. Agron.* **18**, 97-99.

Marian. (1987).

Maurya, P.R. and R. Lal. (1979). No-tillage system for crop production on an Ultisol in Eastern Nigeria. In *Soil Tillage and Crop Production*, R. Lal (ed.). IITA, Ibadan, Nigeria, Proc. Series No. 2, pp. 207-219.

Midmore, D.J. (1991).

Miller and Martin. (1990).

Miller and Martin. (1990).

Morgan, W.B. (1955). Farming practice settlement pattern and population density in Southeastern Nigeria. *Geogr. J.* 121, 138.

Nair, G.M., C.S. Ravindran, and M. Prasad. (1984). Cultural practices for tuber crops. *Indian Farming* 33, 29-33.

Nwosu, N.A. (1973). Some indigenous cropping systems in Eastern Nigeria. In *Proceedings of the 3rd Symposium International Society Tropical Root Crops.* IITA, Ibadan, Nigeria.

Obi, M.E. and P.C. Nnabude. (1988). The effects of different management practices in the physical properties of a sandy loam in Southern Nigeria. *Soil and Tillage Research* 12, 81-90.

Ohiri, A.C. (1983). Evaluation of tillage systems on cassava grown under mulch and their effects on soil organic carbon. In *Cassava Program Annual Report 1983*, National Root Crops Research Institute, Umudike, Nigeria, pp. 22-26.

Ohiri, A.C. (1984). Project 3: Cultural and soil fertility management studies. Tillage and mulch effects on soil water. In *Cassava Improvement Studies, Annual Research Report*, National Root Crops Research Institute, Umudike, Nigeria, pp. 27-28.

Ohiri, A.C. and H.C. Ezumah. (1990). Tillage effects on cassava (*Manihot esculenta*) production and some soil properties. *Soil and Tillage Research* 17, 221-229.

Ohiri, A.C. and J.U. Nwokoye. (1984). Soil physical and chemical properties suitable for yam (*Dioscorea rotundata*) production in Southeastern Nigeria. In *Proceedings of the 6th Symposium International Society Tropical Root Crops*, Feb. 21-26, Lima, Peru, pp. 618.

Okigbo, B.N. (1978). *Cropping Systems and Related Research in Africa.* Assoc. Advancement of Agricultural Science in Africa (AAASA), Publ. Series OT-1, Addis Ababa, Ethiopia. 81 pp.

Okigbo, B.N. (1979). Effects of preplanting cultivation and mulching on the yield and performance of cassava (*Manihot esculenta*). In *Soil Tillage and Crop Production*, R. Lal (ed.). Proc. Series No. 2, IITA, Ibadan, Nigeria, pp. 75-92.

Onwueme, I.C. (1978). *The Tropical Tuber Crops: Yams, Cassava, Sweet Potato and Cocoyams.* John Wiley and Sons, New York, NY, USA.

Opara-Nadi, O. and R. Lal. (1987a). Effects of plant population on soil structure, soil moisture depletion and on yield of cassava (*Manihot esculenta*) on an Ultisol in Southeastern Nigeria. *Soil and Tillage Research* (Need vol., pp.)

Opara-Nadi, O. and R. Lal. (1987b). Effects of no-till and disc plowing with and without residue mulch on tropical root crops in Southeastern Nigeria. *Soil and Tillage Research* **9**, 231-240.

Pardales, J.L., Jr. (1985). Influence of preplanting tillage system on the dry matter and nitrogen accumulations of cassava. *Phil. J. Crop Sci.* **10**, 147-152.

Pardales, J.R., Jr. and F.G. Villamayor, Jr. (1983). Cultural management studies on upland taro. Effects of cultivation systems on growth and yield of taro and incidence of associated weeds. *Ann. Trop. Res.* **5**, 13-22.

Plucknett, D.L., H.C. Ezumah, and R.S. de la Pena. (1973). Mechanization of taro (*C. esculenta*) culture in Hawaii. In *Proc. of the 3rd Symposium International Society Tropical Root Crops*, Ibadan, Nigeria, pp. 286-292.

Raros, R.S. (1985). Evaluation and development of hillside farming techniques for root crop production. Terminal Report, ViSCA, Dept. Forestry, Baybay, Leyte, 29 pp.

Ravindran, C.S. and C.R. Mohankumar. (1985). Effect of method of land preparation and depth of planting on yield of sweet potatoes. In *Tropical Tuber Crops Production and Utilization*, T. Ramanujam *et al.* (eds.). Proc. Nat. Symp. Prod. Util. Trop. Tuber Crops, Nov. 27-29, CTCRI, Trivandrum, India, pp. 129-133.

Roca and D.J. Midmore. (1982).

Seixas, B.L.S. (1976). Preparo do solo. In *Primeiro Curso Intensivo Nacional de Mandioca*, EMBRAPA-CNPMF, Cruz das Almas, Bahia, Brazil, pp. 183-199.

Sinthuprama, S. (1980). Cassava planting systems in Asia. In *Cassava Cultural Practices*, E.J. Weber, J.C. Toro, and M. Graham (eds.). Proc. Workshop, March 18-21, Salvador, Bahia, Brazil. IDRC-151e, Ottawa, Ontario, Canada, pp. 50-53.

Sinthuprama, S. and C. Tiraporn. (1986). Improving the productivity of cassava in Thailand. In *Cassava in Asia, Its Potential and Research Development Needs.* Proc. Regional Workshop, June 5-8, Bangkok, Thailand, pp. 277-287.

Sterrett and Savage. (1989).

Takyi, S.Y. (1974). Effects of nitrogen, planting method, and seed bed type on yield of cassava (*Manihot esculenta*). *Ghana J. Agric. Sci.* 7, 69-73.

Tongglum, A., C. Tiraporn, and S. Sinthuprama. (1988). Cassava cultural practice research in Thailand. In *Cassava Breeding and Agronomy Research in Asia*, R.H. Howeler and K. Kawano (eds.). Proc. Regional Workshop, Oct. 26-28, Rayong, Thailand, pp. 131-144.

Tongglum, A., V. Vichukit, S. Jantawat, c. Sittibusaya, C. Tiraporn, S. Sinthuprama, and R.H. Howeler. (1991). Recent progress in cassava agronomy research in Thailand. In *Proceedings of the 3rd Asian Cassava Workshop*, Oct. 22-27, Malang, Indonesia (*in press*).

Unamma, R.P.A., S.O. Odurukwe, H.E. Okereke, L.S.O. Eno, and O.O. Okoli. (1985). *Farming Systems in Nigeria: Report of the Benchmark Survey of the Farming Systems in the Eastern Agricultural Zone of Nigeria.* Agric. Ext. Res. Liaison Services, NRCRI, Umudike, Umuahia, Nigeria.

Utomo, W.H. and G. Guritno. (1984). Effect of tillage practice and mulching on soil physical properties and yield of cassava in mixed cropping. Paper presented to the 5th Asian Soil Conference, June 10-23, Bangkok, Thailand.

Vangessel and Renner. (1990).

Verapattananirund, P., T. Na Nagara, C. Tongyai, and S. Nualla-ong. (1990). A promising low-input management to sustain high cassava yields in Northeast Thailand. In *Proceedings of the 8th Symposium International Society Tropical Root Crops*, R. Howeler (ed.), Oct. 30-Nov. 5, Bangkok, Thailand, pp. 270-278.

Villanueva, M.R. (1985a). Technology for cassava production in Southeast Asia. *Radix* 7, 8-12.

Villanueva, M.R. (1985b). Technology for sweet potato production in Southeast Asia. *Radix* 7, 8-12.

Villanueva, M.R. (1986). Technology for yam and taro production in Southeast Asia. *Radix* 8, 1-6.

Villamayor, F.G., Jr. (1987). State of the art cassava production technology. Paper presented at Root Crop Anniversary Symp., March 24, PRCRTC, ViSCA, Baybay, Leyte, Philippines.

Villamayor, F.G., Jr. and V.L. Reoma. (1987). Effect of land preparation and post planting tillage on weed control and cassava yield. *Ann Trop. Res.* 9, 185-199.

Vine, P.N. (1980). Soil management for cassava. In *NAFPP Proceedings of the 4th National Cassava Workshop*, National Root Crops Research Institute, Umudike, Nigeria, pp. 115-119.

Vine, P.N., O.B. Ajayi, D.M. Mitchozounou, E.J. Hounkpatin, and T. Hounkpevi. (1984). Soil-conserving techniques in cassava and yam production. In *Proceedings of the 2nd Triennial Symposium International Society Tropical Root Crops — Africa Branch*, Aug. 14-19. Douala, Cameroon, pp. 67-70.

Wallace and Bellinder. (1989).

Wargiono, J. (1984). *Program Report on Cassava and Sweet Potato Agronomy.* Proyek PPE and PE BPP Teknologi Lampung, 206 pp.

Wood. (1937).

Wurr. (198__).

Zheng, X., X. Lin, W. Zhang, F. Ye, and Y. Tian. (1991). Recent progress in cassava varietal and agronomy research in China. In *Proceedings of the 3rd Asian Cassava Workshop*, Oct. 22-27, Malang, Indonesia (*in press*).

Table 1. Harvested area ('000 ha) of root crops in various regions of the world in 1989.

Region	Potato	Cassava	Sweet Potato	Yam	Taro
Africa	779	8,346	1,184	2,699	884
North/Central America	735	192	189	60	2
South America	912	2,380	151	47	1
Asia	4,607	4,053	7,579	15	151
Oceania	48	17	119	18	43
Europe and USSR	10,990	–	7	–	–
World	18,071	14,988	9,247	2,539	1,081

Source: FAO, 1990.

Table 2. Major root crops based on multiple cropping systems in tropical Africa.

Cropping Pattern	Geographical area	Source
1) Cassava + maize followed by (fb) cassava fb fallow	S.W. Nigeria, Togo, Rep. of Bening, Ghana, E. Nigeria	Okigbo, 1977; Ezumah *et al.*, 1987
2) Cassava + yam + maize fb cassava + maize + vegetables fb cocoyam	E. Nigeria, W. Cameroon	Unamma *et al.*, 1985 Nwosu, 1973
3) Rice + cassava fb rice or sorghum + cassava	Sierra Leone, Liberia, Guinea	Dahniya, 1989
4) Cassava + groundnut fb cassava + groundnut	Zaire, Angola	Ezumah (ed.), 1980 Lutaladio, 198_
5) Sweet potato fb cassava + beans	Rwanda, Burundi	Mulidingabo, 1980 Balasubramanian,
1990		
6) Continuously cropped yam + maize + vegetables fb yam + vegetables, etc.	E. Nigeria, W. Cameroon (compound farms)	Unamma *et al.*, 1985 Okigbo, 1977
7) Cassava + maize fb cassava in banana patches	Mozambique, Tanzania, Uganda	IITA, 1982

Table 3. Effect of tillage and mulching on soil water content (%) in two cassava experiments conducted in Dampit, Malang, Indonesia.

Tillage[1]/mulch	Experiment 1	Experiment 2	
	2 months (10-20 cm depth)	2 months (0-10 cm depth)	4 months (0-10 cm depth)
	soil water content (%)		
Complete, with ridges	6.06 a	35.5 b	17.7 a
Partial, with ridges	6.00 a	33.6 ab	18.9 ab
Complete, without ridges	8.31 b	27.8 a	20.0 b
Partial, without ridges	9.26 b	29.3 a	20.0 b
No mulch	5.86 a	31.2 a	14.4 a
Peanut tops	6.21 a	30.4 a	24.3 a
Rice straw	10.35 b	32.5 a	20.7 b
Maize stalks	9.43 b	32.0 a	19.1 b

[1] Complete = whole field plowed; partial = only planting row (single furrow) plowed.

Source: Utomo and Guritno, 1984.

Table 4

Table 5. Effect of methods of land preparation on the yield of two cassava cultivars in Mondomito, Cauca, Colombia in 1981-82.

Treatments	Root yield (t/ha)	
	CMC 92	MCol 113
Without land preparation	10.8	10.4
Hand preparation of planting holes (with hoe)	17.9	12.3
Preparation with oxen-drawn plow	16.0	11.6
Oxen-plowing followed by ridging	15.0	10.0
Preparation with tractor-mounted rototiller	15.7	14.1
Rototilling followed by ridging	16.8	10.9
Strip preparation with hoe, alternated by 1-meter unprepared strips	12.2	9.7
Strip preparation with rototiller alternated with 1-meter unprepared strips	13.5	9.5
LSD (5%)	4.0	1.8

Source: Howeler and Cadavid, 1984.

Table 6. Effect of method of land preparation on dry soil losses due to erosion and on fresh root yield of cassava planted on 25% slope in SCATC, Hainan, China (1989).

Treatments	Soil loss (t/ha)	Root yield (t/ha)
2 plowing, 2 discing, contour ridging	71	26.3
2 plowing, 2 discing, no ridging	141	26.0
1 plowing, no ridging	91	21.3
4-m wide plowed strip alternated by 1-m strip without preparation	145	23.5
2-m wide plowed strip alternated by 0.5-m strip without preparation	82	22.6
hand preparation of planting holes with hoe	38	25.5
no preparation	60	22.6

* Cultivar SC 205

Source: Zheng *et al.*, 1991.

Table 7. Effect of different methods of soil preparation on the average yield of four cassava cultivars grown in Carimagua, 1985-86.

Method	Root yield (t/ha)
Disc harrow + plow + disc harrow + ridger	17.3 a
Disc harrow + ridger	16.4 a
Disc harrow	12.0 cd
Cassava harvester + ridger	16.7 a
Cassava harvester	15.3 ab
Chissels every 40 cm	12.9 bc
One-meter strips prepared with chissels alternated by one-meter unprepared strips	10.3 d
Without preparation	6.9 e

LSD (5%) Treatments = 2.53; CD**

Source: CIAT, 1988b.

Table 8. Effect of various tillage practices on the yield and dry soil losses due to erosion in a newly opened, high-OM, hillside soil in Panjasugan, Leyte, Philippines.

Land preparation	Yield (t/ha)[1]			Erosion (t/ha)[2]		
	Cassava	Sweet potato	Taro	Cassava	Sweet potato	Taro
Zero tillage	26.2	7.9	15.5	8.5	8.9	29.9
Minimum tillage	28.0	9.6	15.3	11.4	10.4	22.4
Strip cultivation - 25 cm	26.2	8.9	13.9	17.7	16.4	32.0
50 cm	28.5	9.8	14.8	11.6	13.5	23.9
75 cm	27.1	9.5	14.3	9.1	13.4	23.5
Complete cultivation	28.8	11.7	–	15.3	12.4	–
	NS	NS	NS	NS	NS	NS

[1] Average of two crops of cassava and taro, three crops of sweet potato.

[2] Erosion is total of two consecutive crops of cassava or taro, three crops of sweet potatoes, all grow over a two-year period.

Source: Adapted from Abenoja and Baterna, 1982.

Table 9. Effect of cultivation and mulching on cassava root yields (t/ha) of cultivar 02864 at two sites in Zaire.

Cultivation treatment	Mpalukidi (sandy clay loam)		Kimpese (clay loam)	
	Mulch	No mulch	Mulch	No mulch
	cassava root yield (t/ha)			
Flat	21.8	16.1	6.9	5.6
Ridge	17.4	13.9	8.0	4.8
No till	20.7	12.4	3.7	2.7
Mean	19.9	14.1	6.2	5.3
LSD (5%)	2.2	1.9	2.2	2.0

Source: Ezumah and Okigbo, 1980.

Table 10. Effect of land preparation on cassava yield[1] and dry soil loss due to erosion in two experiments in farmers' fields near Mondomo, Cauca, Colombia.

Land preparation	Mondomito[2] Yield (t/ha)	Mondomito[2] Soil loss (t/ha)	Agua Blanca[3] Yield (t/ha)	Agua Blanca[3] Soil loss (t/ha)
Without preparation	28.5	1.9	17.6	9.8
Preparation of 1-m wide strips alternated with 1-m unprepared strips	9.7	1.0	15.6	14.1
Preparation with oxen-drawn plow	21.5	2.4	13.6	22.9

[1] Average yield of three cultivars in each location.

[2] 30% slope, field cleared of weed fallow.

[3] 40-45% slope, field cleared of brush fallow.

Source: CIAT, 1985 and 1988b.

Table 11. Effect of land preparation on cassava yield and dry soil loss due to erosion in two experiments on 8% slope in Pluak Daeng, Thailand.

Land preparation	Cassava yield[1] (t/ha)		Dry soil loss (t/ha)	
	1988	1989	1988	1989
Without preparation	27.3	14.3	49.3	13.9
Subsoiler	13.8	–	66.4	–
Cassava harvesting implement	19.3	11.8	46.5	10.2
3-disc plow	26.7	–	55.1	–
7-disc harrow	17.5	–	98.5	–
3-disc plow + 7-disc harrow	29.9	10.8	34.9	18.8
7-disc harrow twice	21.2	–	47.8	–
3-disc plow + 7-disc harrow + up-down ridge	–	12.7	–	20.7
7-disc harrow twice + up-down ridge	32.9	–	60.5	–
3-disc plow + 7-disc harrow + contour ridge	–	12.4	–	16.4
7-disc harrow twice + contour ridge	27.1	–	25.7	–
LSD (0.05)		3.18		10.59

[1] Fresh root yield of cultivar Rayong 1.

Source: Tonglum *et al.*, 1991.

Table 12. Effect of tillage on cassava root yield (t/ha) in CTCRI, Trivandrum, India.

Plowing/digging		Number of earthings up*				
		0	1	2	3	$\bar{x}$
Tractor plowing –	Once	16.2	22.1	24.2	25.1	21.9
	Twice	18.1	22.6	23.5	24.0	22.1
Digging –	Once	14.4	21.6	23.4	25.3	21.2
	Twice	12.7	20.4	25.3	25.6	21.0
Mean		15.3	21.7	24.1	25.0	

CD (0.05) Plowing: NS; Earthing up: 2.51

* This includes weeding.

Source: Mandal and Mohankumar, 1973.

Table 13

Table 14. Effect of land preparation method on the yield of sweet potatoes grown under upland and lowland conditions at CTCRI in Trivandrum, Kerala, India.

Land preparation	Root yield (t/ha)		Vine yield (t/ha)	
	Upland[1]	Lowland	Upland[1]	Lowland
Ridge	17.2	14.8	13.9	12.5
Bed and furrow	16.7	14.9	11.0	11.0
Flat	15.3	13.4	14.6	12.4
Mound	18.6	16.0	12.9	11.4
SE	0.80	1.37	0.99	0.95
CD (0.05)	2.26	NS	NS	NS

[1] Pooled data for two seasons.

Source: Ravindran and Mohankumar, 1985.

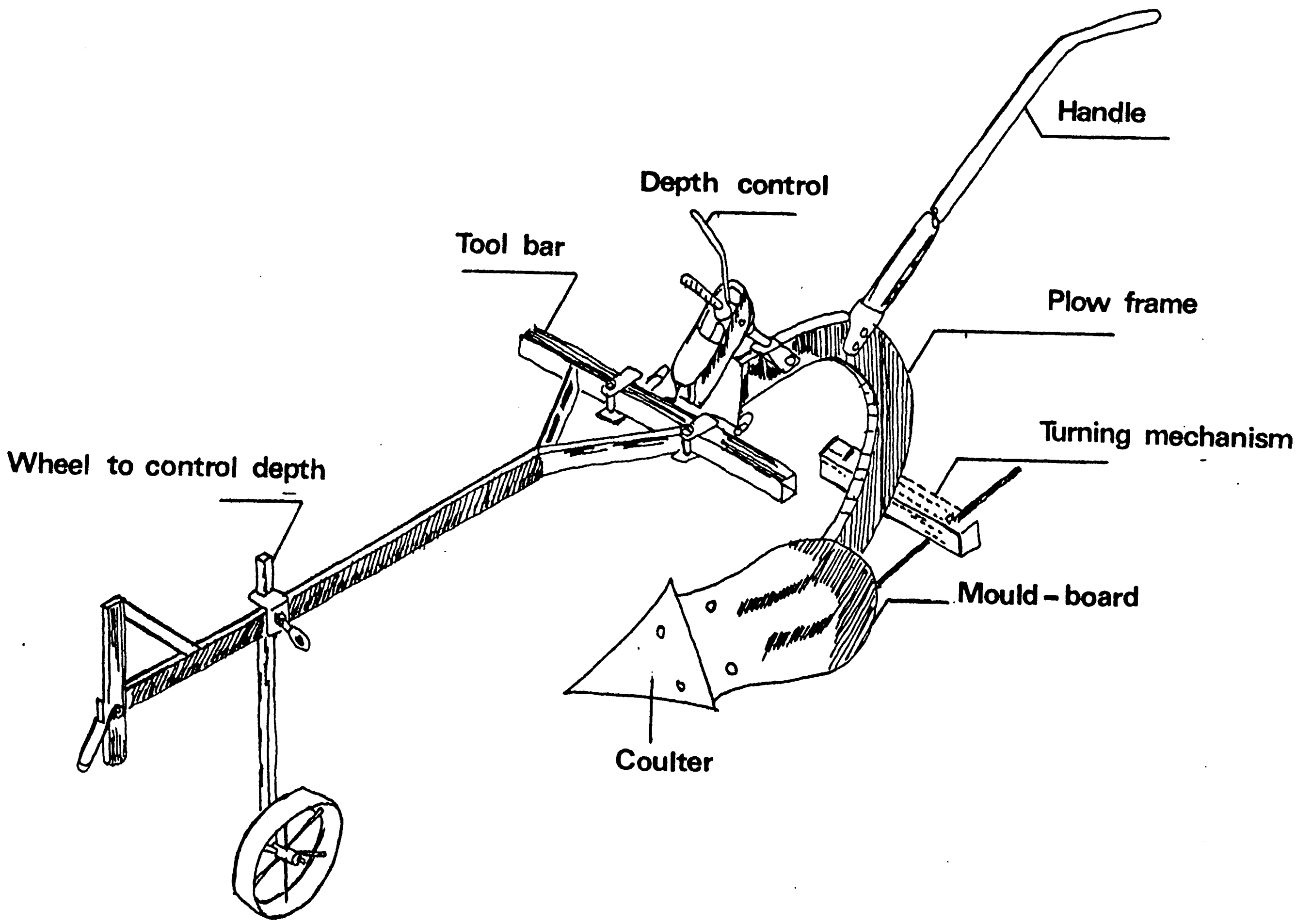


Figure 1. Reversible oxen-drawn plow, used for tilling on steep slopes.
Source: Camacho, 1985.

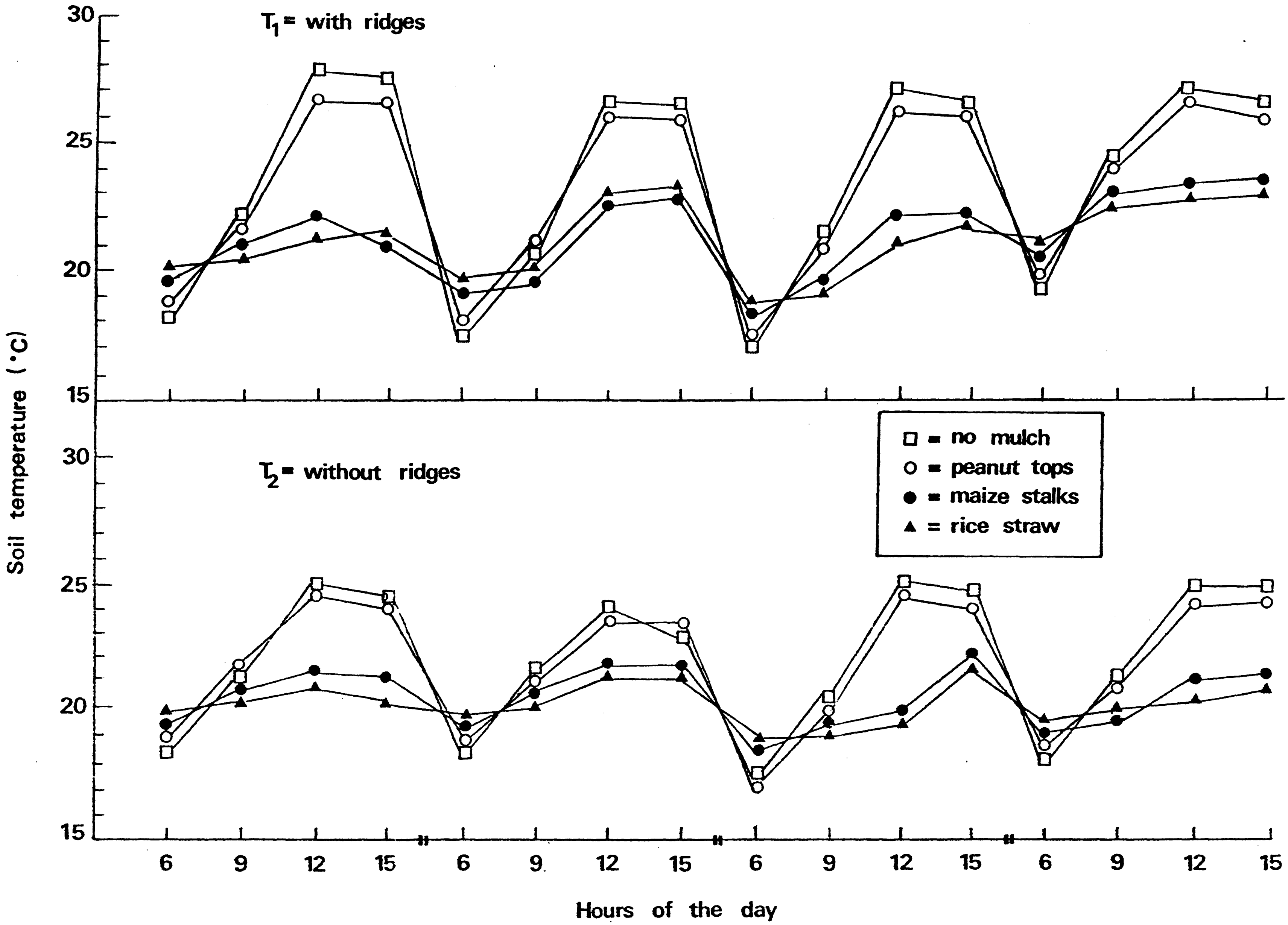


Figure 2. Effect of ridges and the application of mulch on diurnal soil temperature fluctions at 5-10 cm depth in a cassava experiment at Dampit, Malang, Indonesia 1982/83.

Source: Utomo and Guritno, 1984.

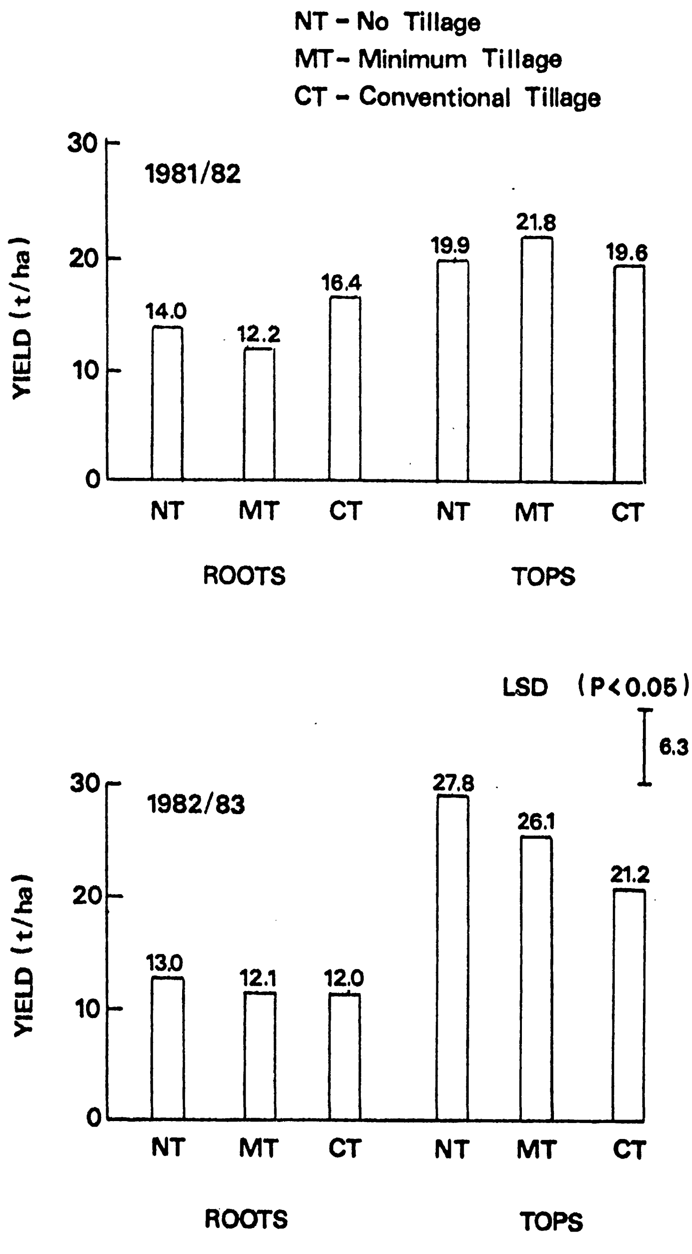


Figure 3. Effect of three tillage systems on root and top yields of two crops of cassava grown in southeast Nigeria (Ohiri and Ezumah, 1990).

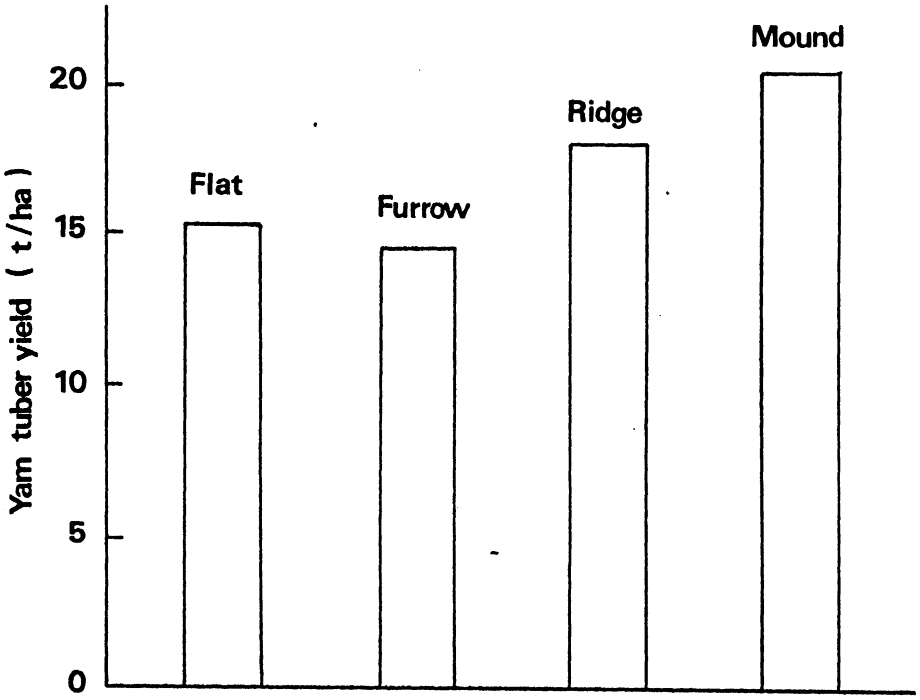


Figure 4. Effect of plant bed configuration on the tuber yield of yam (D. alata) at PRCRTC in Leyte, Philippines.

Source: Villanueva, 1986.

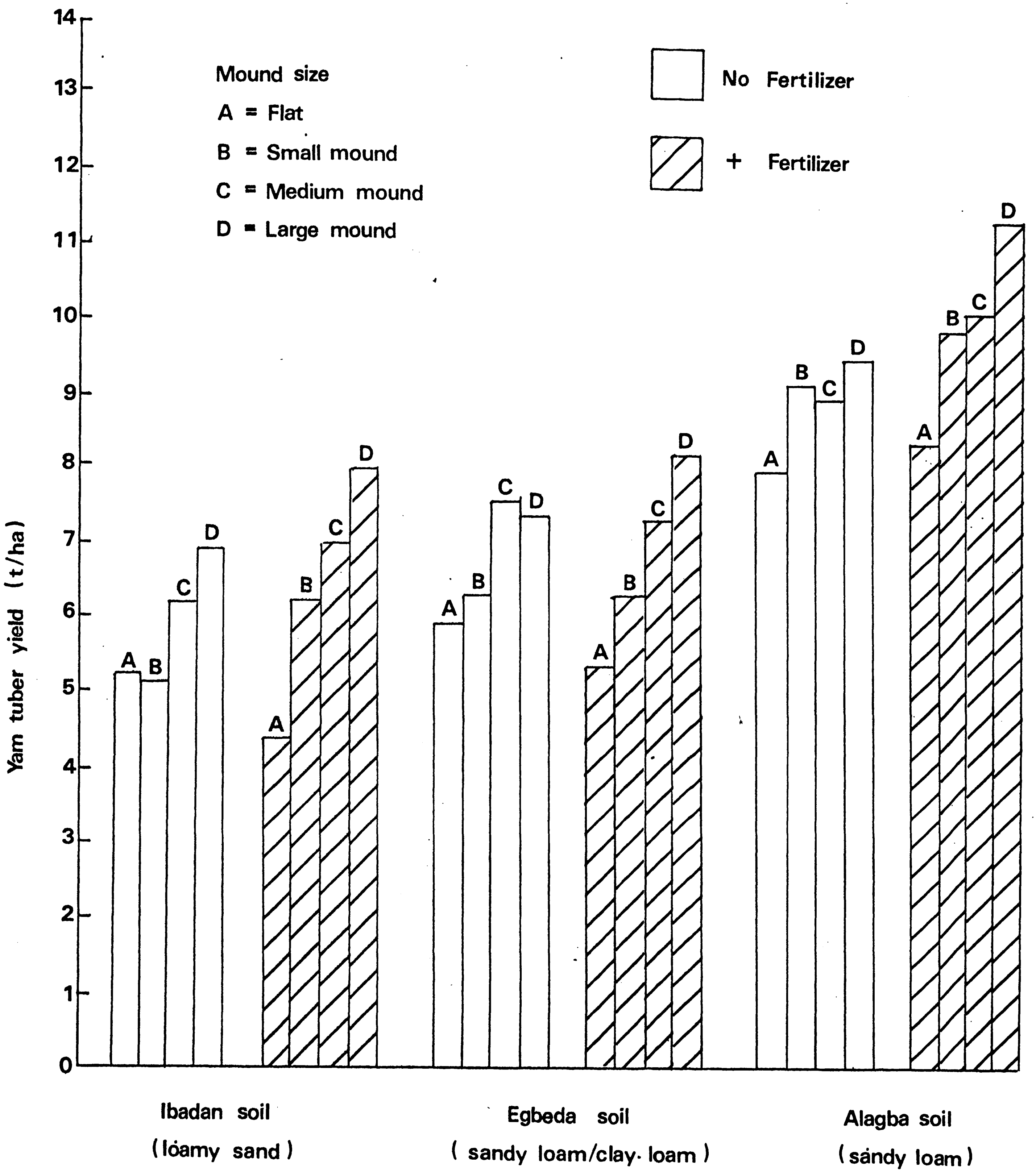
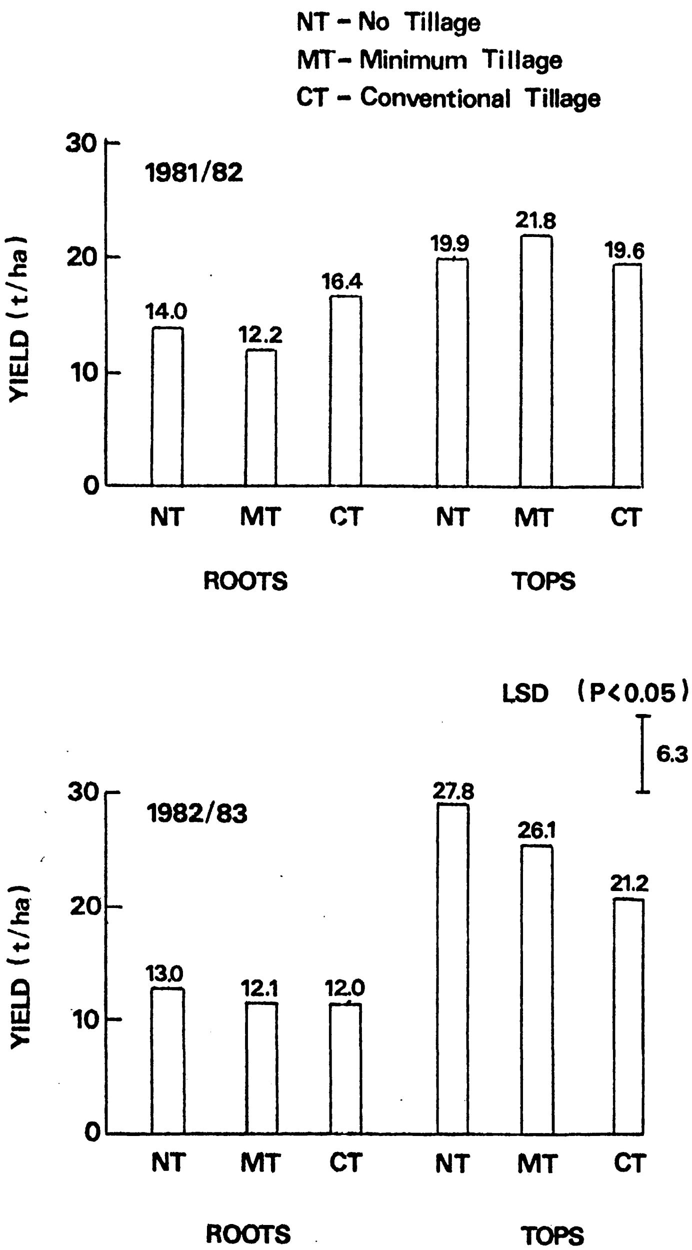


Figure 5. Effect of mounds size and application of fertilizers on the yield of yam (D. rotundata) in three soils of Southern Nigeria.

Source: Kang and Wilson, 1982.



NT - No Tillage
MT- Minimum Tillage
CT - Conventional Tillage
1981/82
YIELD (t/ha)
30
20
10
0
14.0
12.2
16.4
19.9
21.8
19.6
NT
MT
CT
NT
MT
CT
ROOTS
TOPS
LSD (P<0.05)
6.3
1982/83
YIELD (t/ha)
30
20
10
0
13.0
12.1
12.0
27.8
26.1
21.2
NT
MT
CT
NT
MT
CT
ROOTS
TOPS